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Predisposing risk factors for non-contact ACL injuries in military subjects

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Abstract
Purpose The goal of this study was to document the incidence of anterior cruciate ligament (ACL) tears and possible risk factors for these injuries in a large population of young, athletic subjects.
Methods The authors retrospectively reviewed the US Naval Academy's database of midshipmen admitted in 1999 and 2000 ($n = 2{,}345$) and prospectively followed until graduation 4 years later or disenrollment. Excluded were 658 who had a history of preadmission ACL injury or surgery, those without initial radiographs or documented baseline height and weight, or those who had documented contact ACL injuries. Therefore, 1,687 subjects comprised the study group. Standard radiographic measurements, including condylar width, notch width, and femoral notch width index (notch width divided by condyle width), were obtained for all subjects. Statistical analyses were used to determine differences between injured and uninjured subjects.
Results The overall incidence of non-contact ACL injury was 2.9% (37 men, 12 women). The average BMI was 25.6 and 24.4 kg/m^2 for the injured and uninjured groups, respectively ($P < 0.05$). Although femoral notch width alone was not associated with non-contact ACL injuries, subjects with higher than average BMI in combination with narrow notch width were at significant risk for ACL injury ($P = 0.021$).
Conclusions Elevated BMI combined with narrow notch width may predispose young athletes to non-contact ACL injury.
Level of evidence Retrospective comparative study, Level III.

Keywords Knee · ACL · Notch width · Notch width index · BMI

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Introduction

Anterior cruciate ligament (ACL) tears are extremely common in individuals 15–25 years old who participate in athletic activities [10]. It has been estimated that more than 100,000 ACL injuries occur annually in the United States [10, 15]. Despite the frequency of this injury, only a small number of published articles address ACL injury prevention [10, 15, 28]. Anatomic differences among athletes,

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14. ABSTRACT
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15. SUBJECT TERMS

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including joint hyperextension [9, 16–18, 21], subtalar pronation [3, 18], hamstring muscle strength [7–9, 16–18], hamstring tightness [7], quadriceps angle [9, 18], preseason conditioning [4, 5], and gender [2, 4, 6, 11, 19, 20], have all been considered as risk factors for ACL tears. The size and shape of the femoral intercondylar notch and its intimate relationship with the cruciate ligaments have led several authors to consider this anatomic relationship as a particularly important influence on the predisposition for ACL injury [1, 24, 25].

The role of notch width in ACL injury has been studied extensively, but the relationship remains controversial [1, 9, 14, 16, 21, 23, 25]. Several authors have reported that the notch width index, measured as the ratio of the intercondylar notch size to the femoral bicondylar width, is an important predictor for ACL injury [1, 25]. Others have concluded that the notch width index is not a predictor of ACL tear [12, 22]. Still others have shown that the absolute notch width size, and theoretically the corresponding size of the native ACL, is an important indicator of ACL tear [13, 23].

In the largest prospective observational study assessing non-contact ACL injuries to date, Uhorchak et al. [27] followed 895 West Point cadets throughout their 4-year tenure and showed that narrow femoral notch width, generalized joint laxity, and higher than normal body mass index (BMI) in women were risk factors for non-contact ACL injuries [27]. The hypothesis was that both modifiable and non-modifiable risk factors predispose individuals to non-contact ACL injuries. In the current study, the goal was to document the incidence of ACL injuries in a large population of young, athletic subjects, determine gender differences, and evaluate pre-injury radiographic measurements (condylar width, notch width, notch width index) and BMI as possible risk factors for these injuries.

Materials and methods

An existing Institutional Review Board-approved database of all first-year individuals admitted to the US Naval Academy in 1999 and 2000 was retrospectively reviewed, and the midshipmen were prospectively followed until graduation 4 years later or disenrollment. Of those 2,345 individuals, 658 were excluded because of a history of previous ACL injury or surgery by examination or report, failure to have initial knee radiographs or documented baseline height and weight, having an ACL injury secondary to a documented contact incident during the study period, or failure to complete the 4-year program. The final study population consisted of 1,687 subjects (1,434 men and 253 women; median age at admission, 18 years; range, 17–19). For those 1,687 subjects, height (in centimeters) and weight (in kilograms) were normalized by determining the subject's BMI via the following formula: BMI = weight (in kilograms)/height (in meters) squared.

A single investigator evaluated the stability of each subject's knee using standard tests, including Lachman's, pivot shift, anterior drawer, posterior drawer, and varus/valgus stress at 0° and 30° of knee flexion.

Standing posteroanterior flexed weight bearing radiographs of the study group were examined to determine condylar width, notch width, and femoral notch width index (notch width divided by condyle width) using standard measurements. All radiographs were marked and measured by the same investigator. First, a line parallel to the tibial plateau was drawn through the femoral condyles and intercondylar notch at the level of the lateral sulcus. As previously described, this line was used to measure the condylar width of the femur and femoral notch width (Fig. 1) [15, 25]. All radiographic measurements were performed with digital calipers with a precision equal to 0.01 mm. Femoral notch width index was calculated because some researchers have shown an association between small notch width indices and ACL tears [25–27].

From 1999 through 2004, the incidence of non-contact ACL injuries was documented, and the study population was divided into two groups for comparison: those with

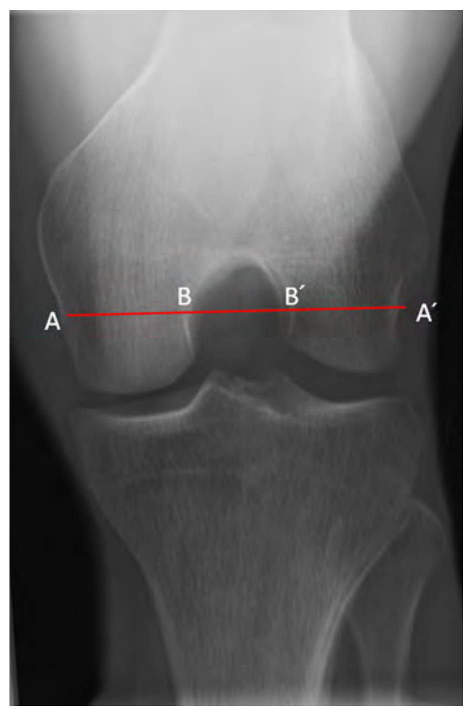

Fig. 1 Tunnel view showing radiographic indices. Femoral condylar width = AA′, femoral notch width = BB′, notch width index = BB′/AA′

and without non-contact ACL injury [15]. The determination of whether an ACL injury was contact or non-contact was based on patient history and accounts from trainers, therapists, and team physicians.

Statistical analysis

Statistical analyses for each risk factor were conducted using SPSS v.15.0 (SPSS Inc., Chicago, IL). A two-tailed P value of <0.05 was considered statistically significant. Statistical differences between mean and continuous variables were evaluated with use of Student's t test. Associations among categorical variables were studied with Fisher's exact test or Chi-squared analysis as appropriate. Primary variables in the study (weight, BMI, and notch width) were dichotomized, and values 1 standard deviation (SD) above the gender-specific mean (weight and BMI) or 1 SD below the gender-specific mean (for notch width) were considered at increased risk of ACL injury. The limited number of covariates of interest in injured individuals precluded cohort multivariate analysis to determine independent predictors of non-contact ACL injury. Lastly, the relative risks of men, women, and all subjects having one or more significant risk factors were calculated.

Results

During the study period, 71 individuals sustained ACL tears, 49 of which were non-contact ACL tears (37 men, 12 women), an overall incidence of 2.9% (2.6% in men and 4.7% in women).

Gender was a significant main effect for the following variables: height, weight, BMI, condylar width, notch width, and notch width index (Table 1). When evaluating risk factors for those with and without ACL injury, the only significant factor was BMI (Table 2). Weight and BMI were significantly different in men with and without ACL injury (Table 3). There was no significant difference in weight and BMI between women with and without ACL injury (Table 4). In this study cohort, notch width, condylar width, and notch width index were not independently associated with non-contact ACL injuries (Table 2). The same association was true for men and women with and without ACL injury (Tables 3 and 4).

The interactions of several primary variables were associated with an increased risk of ACL injury (Table 5). Elevated weight and BMI (values 1 SD above the gender-specific mean) were found to be significant risk factors for ACL injuries in the study cohort and in men specifically. This association was not significant for women. A narrow notch width (1 SD below the gender-specific mean) alone was not associated with an increased risk of ACL injuries in men or women, but a narrow notch width combined with an elevated BMI was found to be a significant risk factor for an ACL injury in all subjects.

Table 1 Comparison of risk factors by gender

Risk factor	Men (n = 1,434)	Women (n = 253)	P
Height (mean cm ± SD)	179.3 ± 6.9	166.3 ± 6.1	<0.001
Weight (mean kg ± SD)	80.5 ± 11.9	64.4 ± 8.5	<0.001
BMI (mean ± SD)	24.7 ± 2.9	23.0 ± 2.3	<0.001
Condylar width (mean mm ± SD)	91.7 ± 5.8	79.7 ± 5.1	<0.001
Notch width (mean mm ± SD)	18.3 ± 3.0	15.6 ± 2.5	<0.001
Notch width index	0.2 ± 0.03	0.19 ± 0.02	0.04

Table 2 Comparison of risk factors in all subjects with and without non-contact injury

Risk factor	With ACL injury (n = 49)	Without ACL injury (n = 1,638)	P
Height (mean cm ± SD)	175.9 ± 8.7	177.4 ± 8.2	N.S.
Weight (mean kg ± SD)	80.7 ± 17.3	78.0 ± 12.7	N.S.
BMI (mean ± SD)	25.6 ± 3.6	24.4 ± 2.9	0.005
Condylar width (mean mm ± SD)	89.2 ± 8.3	89.9 ± 7.1	N.S.
Notch width (mean mm ± SD)	17.3 ± 3.2	17.9 ± 3.1	N.S.
Notch width index	0.2 ± 0.02	0.2 ± 0.03	N.S.

Table 3 Comparison of risk factors for men with and without non-contact ACL injury

Risk factor	With ACL injury (n = 37)	Without ACL injury (n = 1,397)	P
Height (mean cm ± SD)	178.6 ± 8.0	179.3 ± 6.9	N.S.
Weight (mean kg ± SD)	86.1 ± 16.4	80.3 ± 11.8	0.004
BMI (mean ± SD)	26.5 ± 3.5	24.7 ± 2.9	<0.001
Condylar width (mean mm ± SD)	92.1 ± 7.0	91.7 ± 5.8	N.S.
Notch width (mean mm ± SD)	18.1 ± 3.1	18.3 ± 3.0	N.S.
Notch width index	0.2 ± 0.02	0.2 ± 0.03	N.S.

Table 4 Comparison of risk factors for women with and without non-contact ACL injury

Risk factor	With ACL injury (n = 12)	Without ACL injury (n = 241)	P
Height (mean cm ± SD)	167.5 ± 4.4	166.3 ± 6.1	N.S.
Weight (mean kg ± SD)	64.5 ± 6.6	64.4 ± 8.6	N.S.
BMI (mean ± SD)	22.7 ± 2.1	23.0 ± 2.3	N.S.
Condylar width (mean mm ± SD)	80.7 ± 5.3	79.6 ± 5.1	N.S.
Notch width (mean mm ± SD)	14.8 ± 2.3	15.7 ± 2.5	N.S.
Notch width index	0.18 ± 0.03	0.2 ± 0.03	N.S.

Table 5 Interactions of primary variables

Risk factor(s)	P		
	All subjects (n = 1,687)	Men (n = 1,434)	Women (n = 253)
Elevated BMI (1 SD ≥ mean)	0.007	0.03	N.S.
Narrow notch width (1 SD ≤ mean)	N.S.	N.S.	N.S.
Narrow notch width (1 SD ≤ mean) + elevated BMI (1 SD ≥ mean)	0.021	0.037	0.016

Table 6 Relative risk of one or more risk factors for non-contact ACL injury

Risk factor(s)	Relative risk		
	All subjects (n = 1,687)	Men (n = 1,434)	Women (n = 253)
Elevated BMI (1 SD ≥ mean)	2.6	3.2	1.0
Narrow notch width (1 SD ≤ mean)	1.1	0.8	1.3
Narrow notch width (1 SD ≤ mean) + elevated BMI (1 SD ≥ mean)	2.0	2.2	2.0

The relative risk ratios associated with having one or more risk factors varied in men, women, and all subjects (Table 6). The risk ratios for having a low notch width were similar between men and women. The risk ratios associated with having an elevated BMI were higher for men than for women. In addition, the relative risk associated with the combination of a low notch width and an elevated BMI showed a twofold increased risk in men and women.

Discussion

In this study, a retrospective analysis of prospectively obtained clinical and radiographic data on two consecutive classes at the US Naval Academy during a 5-year period (1999–2004) was performed. The most important finding of the current study was that elevated BMI combined with narrow notch width may predispose young athletes to non-contact ACL injury. All non-contact ACL tears were successfully identified in the study population. There were 49 ACL injuries in 1,678 subjects, an overall incidence of 2.9%; the incidence by gender was 2.6% (37/1,434) for men and 4.7% (12/253) for women. These incidences are consistent with those in a previous study that compared non-contact ACL injury incidences in men and women engaged in similar sports or activities [11]. That study did not include ACL injuries sustained in collegiate football or wrestling, which are exclusive to participation by men. The relatively large study population consisting of 1,678 young athletes with 49 ACL tears in a highly controlled setting makes the findings of this study clinically significant.

A prospective study of West Point cadets by Uhorchak et al. [27] found that a combination of non-modifiable factors, such as narrow femoral notch and generalized joint laxity, were significant risk factors for the development of a non-contact ACL injury in men and women. Several other studies have also documented the relationship between a narrow femoral notch width and a higher incidence of non-contact ACL injuries [1, 24, 25]. Some authors have suggested that non-contact ACL injuries may be attributed to a combination of a smaller absolute size ACL and a narrow femoral notch width [10, 23, 27]. Gender is also considered an important factor, with some literature suggesting that women have an increased tendency toward knee injuries, specifically ACL tears [2, 4, 6, 11, 19, 20]. The National Collegiate Athletic Association evaluated the gender-specific incidence of ACL tears in men and women's collegiate basketball and soccer programs and found that women in these settings were two to eight times more likely to sustain ACL injuries [2].

Uhorchak et al. [27] also found that all eight of their female cadets who had some combination of risk factors (narrow femoral notch, generalized joint laxity, higher than normal BMI [i.e., 1 SD above the gender-specific mean], increased knee laxity measured on standard arthrometer) sustained non-contact ACL injuries. In contrast, despite having a greater number of women with ACL injuries (12) in the present study's cohort, it was found that ACL injury was not significantly associated with any demographic variable or radiographic index in women, although it was significantly associated with weight and BMI in men. In the West Point study, the only significant risk factors for ACL injuries in men were radiographic indices (notch width and

notch width index, and eminence width and eminence width index) and joint laxity [27]. As a result, the authors concluded that although the risk factors for ACL injuries in men may be less predictive and multifactorial, a specific combination of risk factors may be more predictive of ACL injuries in the knees of women [27]. In the current cohort, an elevated BMI and weight alone or in combination with a narrow notch width were predictive of ACL injury in men, and elevated BMI in combination with narrow notch width were the only predictors of ACL injury in women. This finding is supported by the fact that there was a twofold increase in risk associated with the combination of a low notch width and an elevated BMI in men and women who sustained non-contact ACL injuries.

The strength of the current study is the inclusion of a large number of young, healthy, and physically fit subjects with well-documented demographic and radiographic indices. Although the original data were collected prospectively and the subjects were followed prospectively, the data review was retrospective, which introduces inherent biases, a major limitation of this study. As a result, one non-modifiable variable (joint laxity) that was measured in previous reports was not included in the current study. Although this exclusion precludes a direct comparison between combinations of risk factors for ACL injury in the present study and the West Point study, the latter identified joint laxity as a non-significant independent predictor of ACL injury in men or women [20].

Additionally, BMI was measured only on admission, despite subjects being followed for 4 years. It is possible that the measured BMI was not a true measure of BMI at the time of ACL injury. However, given the statistical significance of BMI in this study cohort, both alone and in combination with other factors, BMI should be considered a meaningful risk factor for non-contact ACL injuries in this patient population. BMI is an easily calculated measurement that reflects, in general terms, size. For the general population, elevated BMI typically represents obesity. However, in a young, healthy, fit, and athletic population, such as the subjects of the present study, elevated BMI probably represents more lean body mass and greater strength. Although modifying BMI in the general population may be health beneficial, lowering BMI in a young, fit population may not improve athletic performance.

Conclusion

In conclusion, the only significant, modifiable risk factors for non-contact ACL injury were related to weight and BMI. This correlation was more significant in men than in women. No radiographic indices (condylar width, notch width, or notch width index) were independently associated with an increased risk of non-contact ACL injuries. However, the combination of an elevated BMI in the presence of a narrow femoral notch width was significant for non-contact ACL injury in men and women. These findings support the observation that the cause of ACL injuries in men and women is varied and multifactorial and that it cannot be predicted by a single index or measurement. Recognition of the predisposing factors for non-contact ACL injuries will allow clinicians to more effectively identify, counsel, and treat individuals at risk.

Conflict of interest The authors declare that they have no conflict of interest.

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